Explosive Channeling in Submerged Soils

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LONG-TERM GOALS

This research is an integral part of the Surf Zone Explosive Modeling task spearheaded by Naval researchers at the Indian Head Division of the Naval Surface Warfare Center (NSWC/IHD) and the Naval Research Lab (NRL). The joint, long-term goal of the research effort is to develop a reliable predictive methodology of general applicability for predicting the sizes of craters and channels produced in the surf zone by underwater explosions of single charges, lines of charges, and continuous charges. The role of the University of Maryland is to conduct a range of small model tests (both at 1g and at greater than 1g), to develop data that can be used in predicting full scale cratering directly, as well as providing data useful in development of the numerical model by NSWC/IHD and in validating the hydrocode being developed by NRL.

OBJECTIVES

The small-scale explosive physical model tests conducted at the University of Maryland were designed to fulfill the following objectives:

1. Determine the effects of the depth of burial of the charge, the height of water above the soil, and the soil properties (i.e., sand gradation, soil type, and amount of fine particles) on explosive crater sizes. In the case of lines of charges, the effect of charge location and detonation times on resulting channel size are also being investigated.
2. Define the mechanisms involved in cratering under water.
3. Provide a database for validating the incompressible hydrocode being developed by NRL.
4. Provide a database of small-scale craters that can be used in developing an empirical predictive methodology.

APPROACH

Small-scale explosive experiments are conducted at 1-g and under high gravitational levels in the geotechnical centrifuge. Since soil behavior is nonlinear and stress dependent, the geotechnical centrifuge provides a means for creating stress fields in the small models under high gravity levels similar to those that are present in the full-scale prototype. In this way, full-scale blast effects can be correctly simulated in small physical models. Comparison of the results of the tests conducted at 1-g and those conducted in the geotechnical centrifuge provide a means of evaluating the importance of the soil overburden stress. The data also provide a means to determine the appropriate scaling laws for extrapolation of the results of the small-scale 1-g models to full-scale blasting. Experiments utilize both single charges to produce single craters, and multiple charges to create continuous channels. The effects of different parameters on the resulting craters and channels are studied.

To shed light on the mechanisms involved in the process of cratering under water, the soil is colored to identify both the apparent and the true craters in three-dimensional tests. Two-dimensional tests are also conducted in a tank fitted with a transparent window to permit high-speed photographs of the cratering and channeling events. These methods allow evaluation of the relative importance of post-explosive events such as wash back, erosion, and water waves in different types of soils.

WORK COMPLETED

A total of 180 small-scale tests were conducted over the past year. The breakdown was as follows: 34 tests in the geotechnical centrifuge (three at 76-g; two at 52-g; three at 43-g, and 26 tests at 26-g); 109 tests at 1-g using a single charge; 21 tests at 1-g employing a row of four charges; six tests at 1-g employing a row of three charges; ten tests employing a row of two charges; and 46 tests utilizing the 2-D box with high-speed photography. Ten different soils were used in the model tests to investigate cratering in a range of grain sizes and properties. Four soils were retrieved from the three sites at which large scale testing was conducted, including: fine-grained, uniform calcareous sand from the Proof & Experimental Establishment test site near Port Wakefield, Australia; silty sand from the Weston-Super-Mare test site in the UK (two different batches); and sand from the Eglin Test Pond in Florida. The other six soils were developed in the laboratory, mixing sands, silts, and clays purchased from different quarries.

All tests were conducted with soil that was submerged. Reynolds RP-80 detonators (203 mg of explosive) were used as the charges in most of the tests. Some tests used multiple RP-80's at the same location, single and multiple RP-83's at the same location (1.1 g of explosive), and RP-1's boosted (4.4 g of explosive). The depth of burial (DOB) ranged from 7.6 cm to –13.7 cm, with the majority of tests performed with zero DOB. The height of water above the sand surface varied from 0 cm to 18 cm, with 4.4 cm and 2.5cm being the most common value. In addition, efforts were made to determine the influence of material parameters on crater and channel development, since this appears to have very significant effects on development of the true and apparent craters. This has been explored by conducting tests on different soil types and by modifying the grain size distributions of these various test soils, and comparing the resulting crater sizes.

RESULTS

One of the major findings is that there are three distinct categories of crater and channel formation differentiated by water height, as a function of charge size. Explosives detonated in shallow water lead to the largest craters. In this case the gas bubble released throws away the water cover, and the resulting true crater is large. When water returns to the site, some soil is swept into the true crater, filling it to some extent. Explosives detonated in deep water cause a large amount of disturbance at the site, but the apparent crater is in general smaller than for the shallow water case. In the very deep water case, the resulting crater is very sensitive to soil type and charge location – a berm rather than a crater may develop. The actual location of the boundaries between these categories is being explored.

Figure 1 presents the results of three-dimensional model testing conducted in the laboratory at 1g in one sand. Charges were varied by a factor of twenty. Figure 1a shows results for crater depths from shallow water and deep-water model tests, all half buried. Shallow or deep-water behavior with increasing explosive weight was insured by keeping HOW / W $^{0.33}$ constant in each series (HOW = height of water; W = explosive weight). Crater widths (Figure 1b) are less sensitive to water depth. HOW / W $^{0.33}$ = 6.5 inches/cube root pounds. For the shallow water case and HOW / W $^{0.33}$ = 32.5 inches/cube root pounds for deep water.

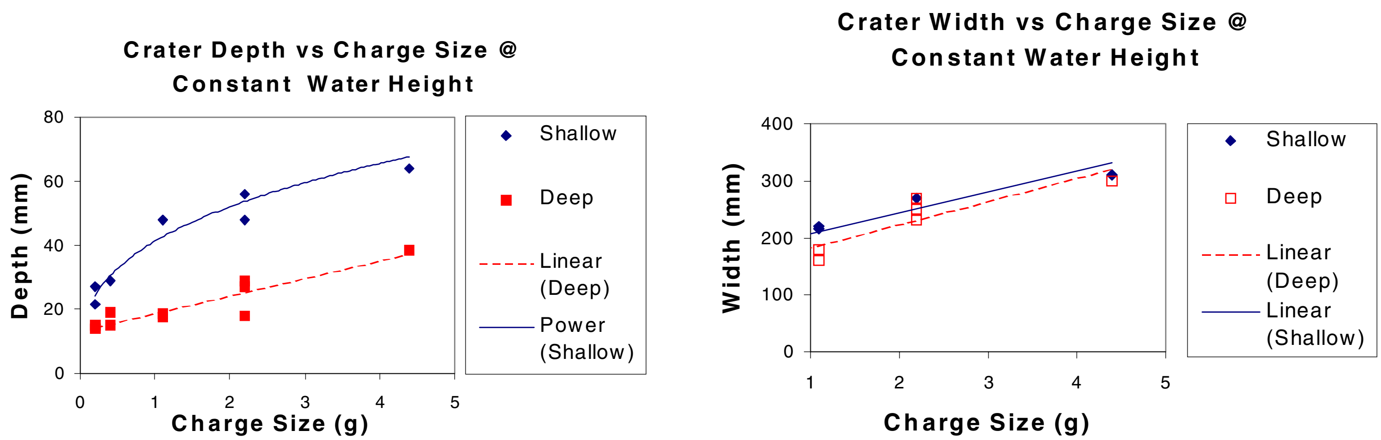
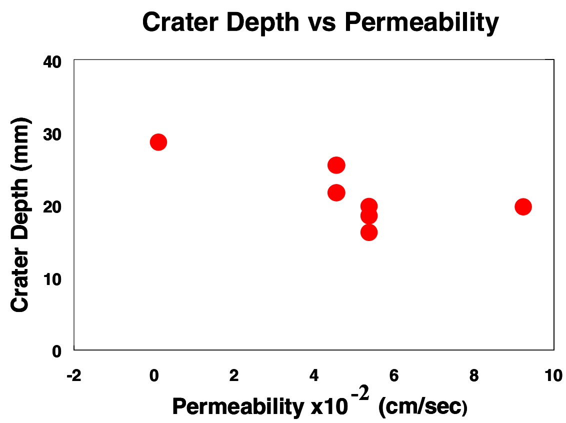


Figure 1. Figure 1a. Crater Depth Versus Charge Size; Figure 1b. Crater width Versus Charge Size.

Soil properties are also important to the crater formed, and we continue to investigate which simple-to-measure soil properties are essential in crater size prediction. We have found fair correlation of crater depths in the shallow water case with permeability; see Figure 2. There is very good correlation between crater depth and 50 percent passing size of the soil in the shallow water case with soils that have little or no silt content. We discussed the importance of the silt content last year and will not repeat it here. Since permeability is a parameter utilized in the bubble code being developed at NRL for use in predicting crater and channel size and particle size is not directly used we are more encouraged by the permeability results.



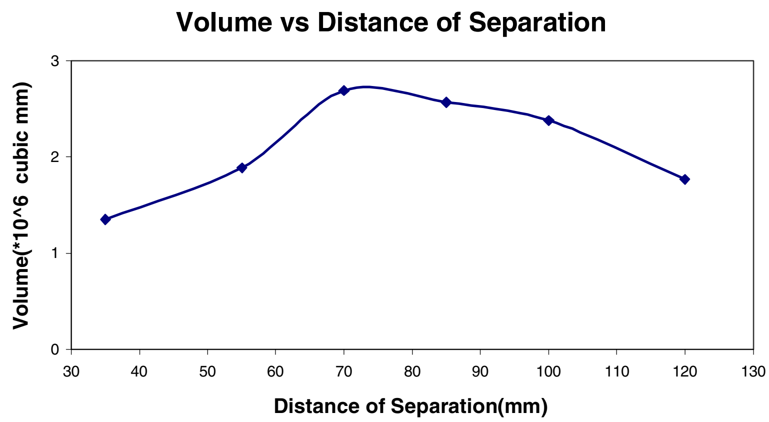


Figure 2. Crater Depth Versus Permeability. *Figure 3. Volume Versus Distance of Separation.*

We have conducted a number of three-dimensional tests to investigate the proper spacing between charges in a line of charges to optimize channel dimensions. We have concentrated on the shallow water case since we feel that is the optimum way to create meaningful channels. It appears that the optimum spacing for simultaneous detonation of charges is equal to the radius of a crater caused by a single charge of the same size; (See Figure 3). Other tests have been conducted which examine acceptable misalignment in charges, which can be tolerated in channel formation. These results are not adequately determined to report on at this time.

We have continued to view crater and channel development in 2-D model tests at 1-g recorded by a high-speed video camera and have applied this very visual tool to the formation of channels from the detonation of a string of charges. Figure 4 shows a sequence of photographs taken in a 2-D test, which had three charges detonated in sequence left to right. Charge timing is controlled according to the stage of bubble expansion. Figure 5 gives a comparison of the channels created with a single charge, three charges detonated simultaneously, and three charges detonated in a delayed sequence. In two dimensional tests, charges detonated in delayed sequence produced channels 70% deeper than channels created from simultaneous detonation of the same amount of explosive. These results have been verified with three-dimensional tests.

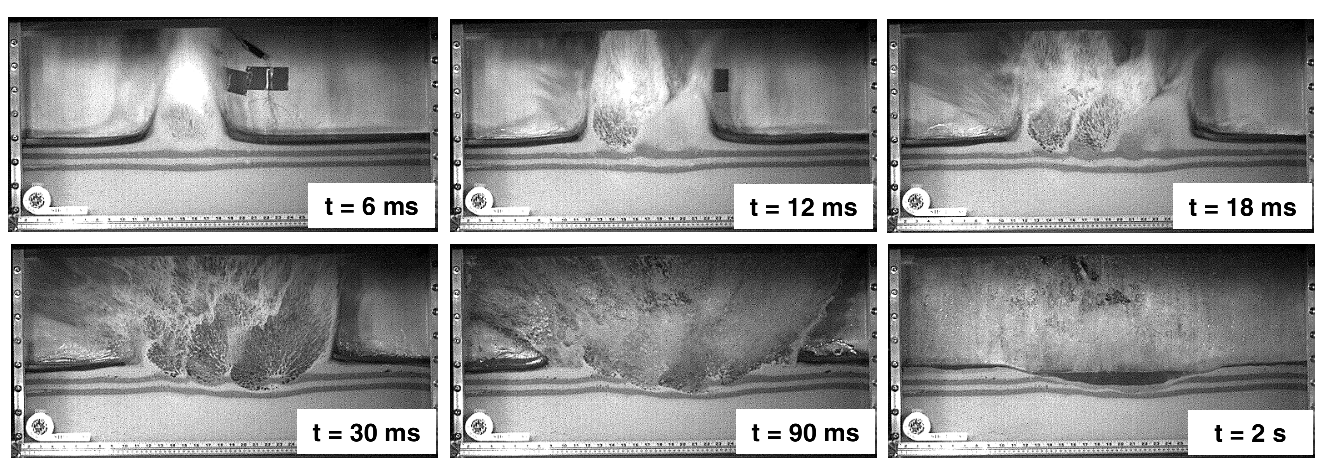


Figure 4. Multiple Charge Test. Three Charges Each 6 ms Delayed; Charge Distance 85 mm

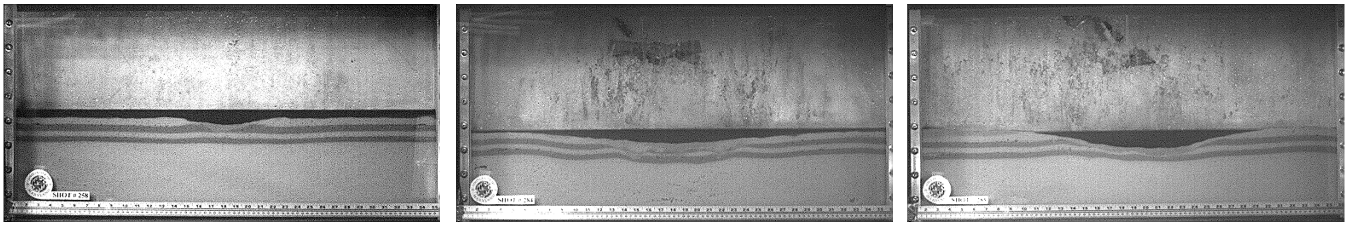


Figure 5. Comparison of Channels with Single Charge. Three Charges Simultaneously; Three Charges Delayed (Left to Right).

Finally, we have conducted high g tests to provide curves that would be useful in predicting crater sizes that could be expected from using larger size charges. The centrifuge allows us to model the effects of radically different size charges by increasing centrifuge acceleration, but leaving model charge size unchanged. Figure 6 shows the results obtained from testing with two soils; charges were half-buried and full-scale water depth modeled was held constant at 0.66 m, which is shallow water. The subscript p stands for prototype. All predictions of the prototype results were from single RP-80 (203 mg) tests.

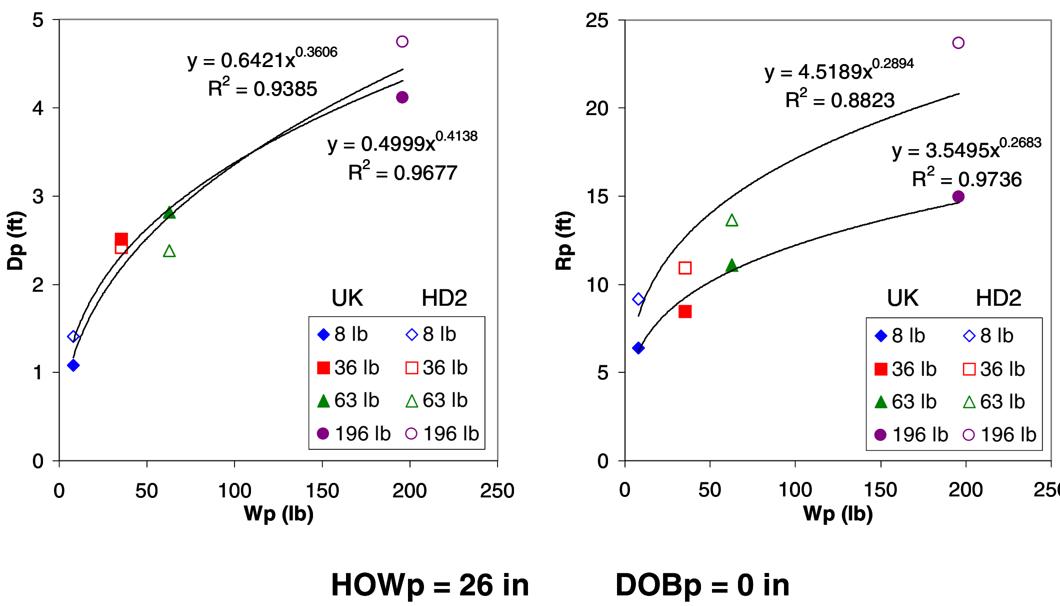


Figure 6. Centrifuge Simulations for Increasing Charge Size

IMPACT/APPLICATIONS

The results of the small-scale explosive experiments in submerged soils show the importance of the site-specific soil properties when explosive cratering or channeling is used under water. Initial results indicate that smaller crater depths should be expected when permeability is large and larger crater depths should be expected when the 50 percent passing size is large. Smaller apparent craters are predicted when water depth is great than for the shallow water case.

The test results also show the importance of charge spacing and timing of detonation in a channeling situation. Understanding these processes and incorporating them in the incompressible hydrocode being developed in a parallel program for modeling channels produced in the surf zone by underwater explosions is essential for accurate prediction of channel size.

TRANSITIONS

The work completed under this task provides the foundation for analytic and computational work being performed under the related task by the Naval Surface Warfare Center, Indian Head Division and the Naval Research Laboratory, respectively. Thus, the transition is directly to NSWC/IHD and NRL. Through those efforts, the basis will be developed for operational forces to properly utilize explosive channeling to breach mine and obstacle fields.

RELATED PROJECTS

As discussed above, work directly related to this task is being performed on modeling explosive channel formation in the surf zone by W.G. Szymczak of NRL and S. Van Denk of NSWC/IHD under an ONR contract.